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**VER (Ag)**

precious Metals," in this vol-

**LIUM (Na)**

a liquid metal heat-transfer fluid for evaporative heat conductor in homopolar so used in vapor lamps for an alloying addition for lead, and as a reactant for deoxidation for reduction of metal flu- highly reactive with water; hy- the reaction is potentially sodium will burn in ambient ys are usually selected as con- of liquid sodium. Argon, he- are used as cover gases to min- dation. Sodium fires are best losing off air accesses or by er nitrogen or inert solids, such s. Commercial extinguishing lium chloride, sodium carbon- phosphate. Carbon tetrachloride lide extinguishers should not

**STRONTIUM (Sr)**

ables beginning on page 1443.

**TANTALUM (Ta)**

ides a combination of properties y refractory metals—excellent w ductile-to-brittle transition high melting point. The largest at this time is in electrolytic ca- e quantities of tantalum also are process equipment (such as heat idensers, thermowells and lined y for handling nitric, hydrochlo- sulfuric acids, and combinations ith many other chemicals. Spin- ding man-made fibers constitute ant application of tantalum. Be- h melting point, tantalum is used ents, heat shields and other com- nances. Tantalum has been in space and nuclear appli- um also is used in prosthetic et with body fluids and as an alloy superalloys, and tantalum carbide t constituent of cemented carbide made from mixtures of titanium, tantalum carbides. Yield and ul- are increased, and ductility is re- eases in the amount of interstitial gen, nitrogen, carbon and hydro- ement of the tantalum can occur if y by these elements is sufficiently purity tantalum (99.90% min) is mercially with the following max- y limits, in ppm: 500 Nb, 300 W, y, 100 Fe, 100 Mo, 50 to 75 C, 50 Ni, 50 Si, 50 Ti, 10 H.

osion behavior. Tantalum oxidizes in 0 °C. It has excellent resistance to a large number of acids, by most ions of salts, by organic chemicals s combinations and mixtures of these y, tantalum exhibits good resistance osive as well as common gases and uid metals.

Compacting pressure, 10 to 85 MPa depending on the physical properties of the powder.

Sintering temperature, 2300 to 2600 °C in high vacuum will essentially remove all detrimental impurities contained in the powder.

**Machinability.** Fully recrystallized unalloyed tantalum has machinability similar to that of soft copper. Use chlorinated hydrocarbons, light oil or water-soluble oil as a cutting fluid, and high speed tool steel or cemented carbide tools. Tantalum can be successfully turned, bored, drilled, tapped, reamed, shaped, milled, sawed and ground to desired tolerances and surface finishes.

**Joining.** Gas tungsten-arc, gas metal-arc, resistance and electron beam welding can be used for joining tantalum. High-purity inert gas (argon or helium) or vacuum must be used in fusion welding. Resistance spot and seam welding can be done in air or under water with proper precautions. Silver brazing alloys, copper, and several specially developed refractory metal brazing alloys can be used to braze tantalum to itself or to dissimilar metals such as stainless steels. Brazing is done in vacuum or under an inert atmosphere (high-purity argon or helium). Tantalum also can be bonded to dissimilar metals by explosive cladding, and in some instances by roll bonding.

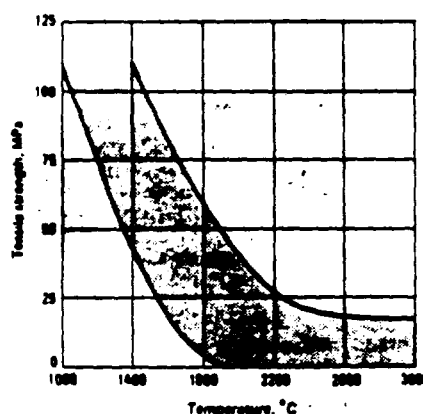
**Cleaning.** To avoid contamination of tantalum by interstitial elements and metallic impurities, it is mandatory that the material be chemically cleaned before any heating operation (such as annealing or welding). Such cleaning involves thorough degreasing (detergent or solvent); chemical etching in 20 vol % HF, 20 vol % H<sub>2</sub>SO<sub>4</sub>, and 60 vol % HNO<sub>3</sub>; hot- and cold-water rinsing (deionized water recommended); and spot-free drying. The etching solution may be strengthened (by adding HF) or weakened (by adding water) to achieve the amount of stock removal necessary to ensure cleanliness.

**Precautions in melting.** Exclude oxygen, hydrogen, nitrogen and carbon. Melt in vacuum or inert atmosphere.

**Hot working temperature.** None; it is worked cold.

**Annealing temperature.** Above 1050 °C in high vacuum for complete recrystallization, with resulting grain size as shown in Table 6

**Maximum reduction between anneals.** Greater than 95%



Note that upper portion of curve is characterized by high strain rates and high interstitial content whereas lower portion of curve is characterized by low strain rates and low interstitial content.

Fig. 4. High-temperature tensile strength of tantalum

Table 8. Tantalum grain size after annealing

| Final annealing temperature (a), °C | Average ASTM grain size (b) |
|-------------------------------------|-----------------------------|
| 1200                                | 5 to 6                      |
| 1300                                | 4                           |
| 1400                                | 3 to 4                      |
| 1425                                | 3 to 4                      |
| 1600                                | 2                           |
| 1700                                | 1                           |
| 1800                                | 0 to 1                      |

(a) Material cold rolled 75% after intermediate annealing, then annealed 1 h at indicated temperature. (b) Determined by comparison with ASTM grain-size chart at 100×.

**Suitable forming methods.** Tantalum can be formed by spinning, deep drawing, bulging, bending, blanking, punching and stretch forming using conventional methods, equipment and tooling normally found in shops fabricating heat-resistant alloys.

**Tensile properties.** See Fig. 4.

**Hardness.** Electron-beam melted, 110 HV; P/M compact, 120 HV

**Poisson's ratio.** 0.35 at 20 °C

**Elastic modulus.** Tension: 186 GPa at 20 °C, 159 GPa at 750 °C. Shear: 69 GPa at 20 °C

**TECHNETIUM (Tc)**

Technetium is used as a radioactive tracer in medicine with potential uses arising from its favorable corrosion-inhibiting properties and its high superconducting transition temperature. There is contamination hazard due to its radioactivity. Classed as moderately toxic. All sample preparation, etc., which could disperse solid <sup>99</sup>Tc must be carried out in glove-box facilities. The data that follow are for <sup>99</sup>Tc only.

**Tensile properties.** Tensile strength, 1510 MPa as-rolled (46% reduction); 798.6 MPa after annealing 10 min at 950 °C; 0.2% offset yield strength, 1290 MPa as-rolled (46% reduction); 319 MPa after annealing 10 min at 950 °C (fully recrystallized); elongation in 1 in.: 4% as-rolled (46% reduction); 30% after annealing 10 min at 950 °C

**Hardness.** 46% cold worked, 394 HV, 442 HB; annealed at 950 °C: 151 HV, 112 HB

**TELLURIUM (Te)**

Tellurium is used as an additive to steel and copper to improve machinability, an additive to cast iron to control depth of chill, in the production of malleable cast iron as a carbide stabilizer, and in lead-base alloys to improve their properties. It is an important constituent of thermoelectric alloys. It is also used in fuses for explosives, as a vulcanizing agent in rubber, as a catalyst in chemical reactions, as a glass-forming agent in glasses, and as a coloring agent in glass and ceramics.

**Tensile strength.** 10.8 to 11.25 MPa

**Hardness.** 25 HB, 2.3 Mohs

**TERBIUM (Tb)**

Terbium is used as a phosphor and in catalysts. It will remain shiny in air at room temperature. Turnings can be ignited and will burn white hot. Finely divided terbium should not be handled in air.

**Tensile properties.** About the same as gadolinium

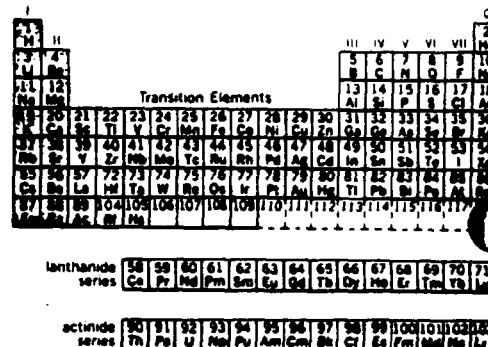
**Hardness.** 38 HV for polycrystalline; 30 HV for

Metals Handbook desk edition 1985 by American Society for Metals

Australia, Commonwealth Council for Scientific and Industrial Research, Australia, 1948; S. P. Parker (ed.), *Synopsis and Classification of Living Organisms*, 2 vols., 1982.

## Thallium

A chemical element, symbol Tl, atomic number 81, relative atomic weight of 204.37, a member of group III and the sixth period of the periodic table. The valence electron notation corresponding to its ground state term is  $6s^26p^1$ , which accounts for the maximum



oxidation state of III in its compounds. Compounds of oxidation state I and apparent oxidation state II are also known.

Thallium occurs in the Earth's crust to the extent of 0.00006%, mainly as a minor constituent in iron, copper, sulfide, and selenide ores. Minerals of thallium are considered rare.

Thallium has significant use in electronic components, such as thallium-activated sodium iodide crystals in photomultiplier tubes. It is also used in low-melting-point alloys, optical glass, and in glass seals for enclosing electronic components. Thallium is being used in research involving high-temperature superconducting systems.

Thallium compounds are toxic to humans and other forms of life. When mixed with food they have been used as rodenticides, although a federal act now prohibits private use of thallium for such purposes. However, the radioisotope thallium-201 has an important application as a radiopharmaceutical in cardiac imaging. Thallium is similar in biochemistry to potassium, and establishes equilibrium with the potassium ions that are normally concentrated within cardiac cells. An approximation of blood flow can be obtained in a cardiac nuclear study using thallium-201.

**Thallium compounds.** The insolubility of thallium(I) chloride, bromide, and iodide permits their preparation by direct precipitation from aqueous solution; the fluoride, on the other hand, is water-soluble. Thallium(I) chloride resembles silver chloride in its photosensitivity.

Thallium halides are not soluble in aqueous ammonia. The solubility of the halides is enhanced in solutions containing an excess of halide ion (X) owing to the formation of  $\text{TlX}_2^-$  and  $\text{TlX}_3^{2-}$  ions. An interesting coordination-number-eight species is obtained when thiourea (Tu) reacts with thallium(I) compounds. The product has the composition  $\text{TlX} \cdot 4\text{Tu}$  and a structure in which each Tl is surrounded



Fig. 2. Colony of *Pyrosoma atlanticum* (Pyrosomida).

by budding from a complex stolon, and colonial, sexually reproducing blastozooids. The order Pyrosomida includes species which form tubular swimming colonies (Fig. 2) and which are often highly luminescent. *Salpa*, *Doliolum*, and *Pyrosoma* are familiar genera. SEE BIOLOGICAL SCIENCE: TUNICATA.

Donald P. Abbott

**Bibliography.** H. Thompson, *Pelagic Tunicates of*

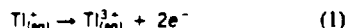
Physical properties of thallium(I) halides, TlX

| Halide | Melting point, °C (°F) | Boiling point, °C (°F) |
|--------|------------------------|------------------------|
| TlF    | 327 (621)              | 655 (1211)             |
| TlCl   | 430 (806)              | 806 (1483)             |
| TlBr   | 456 (853)              | 815 (1499)             |
| TlI    | 440 (824)              | 824 (1512)             |

by eight sulfur atoms at the corners of an antiprism, with each sulfur bonding to two thallium atoms, thus giving chains of thallium atoms perpendicular to the plane bearing the four sulfur atoms. The physical properties of thallium(I) halides are given in the table.

Thallium(I) oxide is a black powder which reacts with water to give a solution from which yellow TlOH can be crystallized. The hydroxide is a strong base and will take up carbon dioxide from the atmosphere. Thallium(I) sulfide can be precipitated from solution. It reacts with molecular oxygen to give a compound of composition  $Tl_2SO_2$ .

Thallium(I) ions can be oxidized to thallium(III) in solution by an oxidizing agent of greater than -1.25 volts, the standard electrode potential for reaction (1).



Studies on the rate and mechanism of reaction lead to the conclusion that this oxidation involves a two-electron transfer process. The magnitude of this potential makes thallium(III) a good oxidizing agent, and in fact it will oxidize water in hot solutions.

When a base is added to a solution of thallium(III), a brown precipitate of  $Tl_2O_3$  is obtained; the hydroxide has been shown to be nonexistent. Thallium(III) oxide decomposes to thallium(I) oxide at 100°C.

The thallium(III) halides are prepared from the oxidation state I halides by reaction with the free halogen. These halides are unstable thermally, decomposing to the oxidation state I halide and the halogen. Thallium(III) fluoride melts at 550°C (1022°F) in an atmosphere of fluorine, but decomposes when heated in air and hydrolyzes in water. The chloride decomposes upon melting at 25°C (77°F), and the bromide shows an appreciable partial pressure of bromine even at room temperature. The iodide of composition  $TlI_3$  is apparently  $(Tl^+)(I_3^-)$  in the solid state. In solution, the thallium(III) chlorospecies have been shown to be  $TlCl_2^+$ ,  $TlCl_3$ ,  $TlCl_4^-$ , and  $TlCl_6^{3-}$  by Raman spectroscopy. The  $TlX_4^-$  ( $X = Cl, Br, I$ ) is tetrahedral, while  $(Li, Na)TlF_6$  has a fluoride structure and does not contain  $TlF_4^-$  ions. The compound of composition  $TlCl_3 \cdot 2py$  actually contains a six-coordinate cation  $[Tl(py)_4Cl_2]^+$  and the  $[TlCl_4]^-$  anion ( $py =$  pyridine). Thallium(III) is also six-coordinate with bidentate sulfur ligand in the species  $Tl(S_2CNEt_2)_3$  and  $[Tl(S_2C_2N_2)_3]^{3-}$ . Six-coordinate thallium is also encountered in  $Tl_2Cl_6^{3-}$ , where two octahedra of chlorine atoms share a common face. Products of composition  $TlX_2$ , which are obtained from the three-state halides by careful decomposition, in reality are  $Tl_3[TlCl_6]$  and  $Tl[TlBr_6]$ .

Thallium forms organometallic compounds of the following general classes,  $R_3Tl$ ,  $R_2TlX$ , and  $RTlX_2$ , where R may be an alkyl or aryl group and X a halogen. The  $R_2TlX$  compounds are ionic and are very stable, being unreactive toward oxygen of the air and

moisture. The  $R_2Tl^+$  ion has been shown to be linear, and is capable of accepting an additional ligand to form a T-shaped species, such as  $[Me_2Tlpy]^+$ . The cation  $(C_6F_5)_2Tl^+$  reacts with dipyrindyl (dipy) to give a compound with apparent coordination number five,  $(C_6H_5)_2Tl(dipy)$ . The trialkyls on the other hand are quite reactive. Triethylthallium, for instance, which may be prepared from diethyl thallium chloride and ethyl lithium, a yellow liquid with a boiling point of 55°C (131°F) at 200 kilopascals, decomposes at 130°C (266°F). Monophenyl dichlorothallium, which is prepared by heating thallium(I) chloride in an aqueous solution of phenylboric acid, tends to decompose to diphenyl compounds and thallium.

A cyclopentadienyl compound of thallium,  $TlC_5H_5$ , is prepared with remarkable ease by passing its vapors of cyclopentadiene into an aqueous solution of thallium(I) hydroxide, whereupon cream crystals of the product precipitate. This compound is monomeric in the vapor state but polymeric in the solid state.

Thallium metal dissolves in alcohols to give tetrameric alkoxides,  $Tl_4(OR)_4$ . The Tl atoms are arranged at the corners of a tetrahedron with the  $OCH_3$  groups perpendicular to the faces and with the oxygen atoms in three coordination to the thallium atoms. *See COORDINATION CHEMISTRY.*

**Analysis.** Thallium can be determined spectroscopically or in solution by oxidimetry. The oxide,  $Tl_2O_3$ , can also be precipitated and carefully dried.

**Thallium metal.** Thallium is recovered from the flue dust of roasting operations of sulfide and selenide ores, especially pyrites. It is extracted from these residues and recovered as the metal by electrolytic reduction of sulfate solutions. Thallium is a white, soft metal with a melting point of 302.5°C (576.5°F), a boiling point of 1460°C (2660°F), and a density of 11.85 g/cm<sup>3</sup> at 20°C. The metal has a hexagonal close-packed structure and a metal radius of 0.171 nanometer.

The metal is capable of being oxidized by hydrogen ion as shown by the standard electrode potential of +0.3363 volt for reaction (2). Usually nitric acid is



used to dissolve thallium, since thallium(I) chloride and sulfate are not very soluble and their formation interferes with the oxidation reaction. Thallium metal reacts with the halogens and nonmetals to form thallium(I) compounds. The rate of reaction is appreciable even at room temperature. *See GALLIUM; INDIUM.*

Edwin M. Larsen

**Bibliography.** F. A. Cotton and G. Wilkinson II, *Advanced Inorganic Chemistry*, 5th ed., 1988; A. G. Sharpe, *Inorganic Chemistry*, 2d ed., 1987.

## Thallobionta

One of the two commonly recognized subkingdoms of plants. In contrast to the more closely knit subkingdom Embryobionta, the Thallobionta (often also called ThallopHYta) are diverse in pigmentation, food reserves, cell-wall structure, and flagellar structure. They still form a natural group, however, in the sense that they are all probably derived from ancestors which would be referred to the Thallobionta, without the intervention of any ancestors which would have to be referred to other groups. The Thallobionta are here considered to include seven divisions, the Rho-